DISCUSSION

Dr. Gene Ives, Chair

Dr. Gene Ives (Sandia National Laboratory): Now I'd like your participation. Any comments or questions that you would like to address to any of the panelists or toward Dr. Burte on the nature of unified life cycle engineering and the role of NDE in that process?

Dr. Michael J. Buckley (Rockwell Science Center): I have a comment.

Well, I had to answer -- it was something to irritate everybody -Harris'' question about a window, and as I was sitting here thinking about it, I said if we could really model processes in a whole operation, NDE will not exist as it exists today. I think we will worry about controlling the process during manufacturing and work very hard to eliminate a separate inspection step because it costs too much. We will also work very hard to eliminate field inspection. We would probably rather have sensors, if it's a flight critical component or something of that nature, on the system.

And then, to ask for a window for NDE in the traditional sense, I think, is solving the wrong problem. Perhaps you would ask for a window by saying "How would I eliminate traditional inspection and build in quality or build in sensors?" And I thought of (bearings), but that's such a specialty area, that's probably not a good one. And I thought of composite, and there's an area that's going to loom in major importance and we inspect it like crazy today, much more so than any other structure on an air frame.

Why don't you try to eliminate that, because you understand it? Start to define what you know about the material and what you don't; control it during manufacturing. The semi-conductor people have to do that. The Japanese have gone that way. If you want to be competitive economically, you pretty well have to build in quality. You can't afford an extra step to inspect it, and you certainly don't want to tear it apart later.

So maybe your window isn't something that people here want to hear, but I think the field is going to change. As we understand these things, you are not going to be climbing over big structures. Anyway, that's one view of the future.

Dr. Bonner Staff (Lockheed): Let me respond a little to the comments just made with a long story and a short question. The short question is: Where are the incentives?

The long story is: About 12 years ago, when we were starting to do our probabilistic work on air frame structure, we came up with a couple of obvious things. There's a minimum size below which you can't find cracks and they don't grow at a constant rate. Those two things taken together say: don't inspect in the middle of your expectd lifetime. When did we inspect? In the middle of our expected lifetime.

We went to the Air Force and said, "Hey, here's some logic that says you can make a bunch of money if you will just change the time at which you conduct your field inspections." This bunch of money represents several airplanes over the life of the fleet. But that was tied in with the liability and the air frame responsibility that went clear back to the basic designs, and the Air Force said to the air frame manufacturer, "We will do this if you will prove to us that there's no risk involved." The responsibility was put on us to change the risk that we already had, and if we were right, they would benefit and we had the privilege of paying for our task. Now I'm back to my question. We are talking about existing field inspections that are going to exist over a long time period. You don't budget over that time period. You don't pay for the kind of work now that's going to reward you in that maintenance budget in the future. Somehow, we are able to do it on the new system designs, but we are still not addressing the cost benefits on a whole bunch of air frames out there that are beginning to suffer from corrosion, for example.

Where is the incentive that causes our system to go to work and apply our technology for the profits that we can make from it?

Dr. Ives: Would any of the panelists care to address that?

Dr. W. G. Clark, Jr. (Westinghouse): I'll address that.

I think your comments are certainly appropriate. Clearly, you know who your customer is and your mode of operation is clearly tied into that. With regard to the area of NDE and the incentive, again, I think your incentive has to clearly be defined by your customer.

In the case of Westinghouse and many different businesses, our incentive for inspectability concerns changes all over the place. If we are making copper hardware to replace in the equipment we built in the '30's, the concern for inspectability there is completely different from what it is for a nuclear reactor. I think you have to balance it against what your customer is prepared to pay for it. If you are letting your customer con you into doing things that you are paying for on your own, then I think that's a problem that maybe, not you, but somebody in your organization has got to look at. Nothing is free. Let's face it.

Dr. Staff: We didn't do it. We continued to inspect mid-life.

Dr. Clark: Right. Well, I think everyone would like to inspect before it's too late. That's my goal: the day before. (Laughter).

Dr. Ives: I would venture that the answer to your question is either an enlightened customer or an enlightenable customer.

Dr. H. M. Burte (Wright-Patterson): Let me pose a question, really, to get off this. We can talk about this business of how we change the manner in which systems are procured in order to throw this in. That's a very real problem. Michael's right. Maybe the toughest one.

Let me pose a question to the panel or to anybody else, and it's really the question that my co-author, Dale Chimenti, has worried about very considerably.

It's rather straightforward to see how our analytic model can feed in, but is there going to be a role for other forms --the question I was posing -- other forms of knowledge, other forms of information handleable by other than the analytic modeling in the NDE? Is that an illusory goal?

Are those just words and pepper dust I was throwing up in posing those questions? Or is there really a way of capturing and codifying this knowledge other than these analytic models so that inspectability can be gathered like this? Dale has worried about that a lot, and I was reflecting some of his concerns, worries and thoughts in the talk.

Dr. Buckley: There hasn't been a lot of work trying to capture the heuristic rules along with analytic models in one program. There is work now beginning in that area, but I think you certainly have to say that people have succeeded in doing that in narrow fields, and that's really the success of expert systems.

We can talk about the pitfalls, though, in this particular application because you want something that is general and will handle a broad class of problems, and all the successes today have been in very narrow fields. I was trying to hint at that potential problem, and I think it is a very fundamental issue that is not going to be solved easily.

I mean, a lot of the formal logic people consider these expert systems a hack because you simply build something to sell on one particular case. You got to be careful about that. You could use a lot of fairly broad-based rules.

Dr. Ives: Comment?

From the Floor: Yes. On the use of expert systems, my impression of the successes that they have had is that they find a solution to a problem; they find a way of handling something that human beings think is a solution. For the system, that's just a string of symbols, but for us, it seems to be a solution.

What we are trying to do here is to avoid a failure in something that we are inspecting. We say it's okay, and then it's not supposed to break. That's a very different search problem, I think. It's not that you find a solution; it's that you somehow find a way past a disaster.

Dr. Buckley: Isn't it a diagnostics problem?

From the Floor: Well, the diagnostics are what the doctors are looking for. A diagnosis, for them, is an identifiable disease and a treatment program.

Dr. Buckley: You could certainly use an example of a life-or-death issue. It could be. Isn't that the same thing as NDE?

From the Floor: No.

Dr. Buckley: In principle?

From the Floor: You are looking at something that appears to be healthy in the case of NDE, and in the case of a medical exam, there are obvious problems. They don't apply their diagnoses, their expert systems, to people who seem to be healthy. (Laughter) And I think that's a big difference.

Dr. Ives: We have a comment here.

Dr. Bob Gilmore (General Electric CRD): Yes. When you inspect, there is a reality: the part is really good enough to serve or it is really not good enough to serve, so that there are given facts. Now, an inspector attempts to establish this fact, and he attempts to establish it through various means of measurement.

For instance, if you inspect one frequency, looking at one amplitude, one threshold, yopu have a very limited perception of this fact, and if you have a complicated part that takes a lot of looking at, you may or may not detect something, and if you detected it, you may or may not characterize it properly. But if you test the thing at many frequencies from many different directions -- you inspect the surfaces and you inspect the bulk and you understand your fields and you understand what your probabilities are -- now you improve your perception of this fact more and more.

Now, there are points where you want to know these things. In the manufacturing cycle, you want to know what the material is good for, and if it's an aircraft engine that has cost you $100 a pound for raw material, you bloody well want to know -- first of all, you don't want any more of it than you have to have, and you bloody well want to know if it's good, and you blasted well want to know if it's good in the high-stress points such as the bore. And as you proceed on with these multiple test procedures, you will improve your perception of the reality of this part, and you are going to use eddy current and you are going to use ultrasound.

Now, after the part has been manufactured, you are going to want to know how it functions in service and you are going to use sensors where sensors are appropriate, in-flight sensors, in-service sensors. But you are also going to use inspections, and each time you do this, you limit your risk, and all these things can be structured in algorithms and all of them can be fed into these expert systems.

But the fact remains that the expert system eliminates one thing only: shut eyes, the lack of a cup of coffee in the morning. The expert system is no better than the expert. It's taking a human being who understands these things, putting them in the software, and removing his fatigue. Every human being in this room qualifies.

Put a team of 200 software engineers, assign them to each one of these individuals; composite the thing into a Cray computer and in one Cray-day, you could probably establish a pretty good perception of reality for the most complex of parts.

Dr. B. L. Crowder (IBM): I'd like to say again, NDE keeps being used, I think, in the final test mode. I'd like to return back to the issue of expert systems. We do a lot of work on that in manufacturing and research.

One of the points about a lot of the expert systems work is that it is, in fact, in its infancy. But the thing that you have to remember is that the expert system also provides a way to capture knowledge. And in, at least, the semiconductor industry, where you don't work just one shift, it turns out that the people who work second and third shift tend, in terms of their abilities, not to be as good as that real expert on first shift.

At the present time, we are really looking at expert systems basically to supplement the lack of skill at second and third shift, not to replace them, necessarily, but to supplement the lack of skill. But eventually, what you can actually do over a long period of time is to make sure that you can somehow codify the knowledge and continue building. In other words, the expert system activity has to be flexible enough so that as more knowledge is gained, it can be easily added to the system.

Dr. James Rose (Ames Lab): I would like to make a comment on the first talk by Dr. Burte which deals with the flaw characterization aspects.

I think this might be quite difficult to get that prior data base that's needed to understand the flaw characteristics, because if you have flaws which occur routinely, you tend to engineer them out. You modify your process; you get rid of them. I mean, we are normally looking at very low probability events with very high cost. That's where NDE is used. And we have almost no handle on what the flaw population is.

But with the jet engine disks, for internal flaws, we would stabilize the characterization of internal flaws there if we had some idea of what the internal flaw population is, but there are so few flaws occurring internally in jet engine disks, that it's just not feasible to get a handle on that population distribution, on what are the possible kinds of flaws. Again, if we did have some handle on it, we would immediately change the engineering process, and we wouldn't have those kinds of flaws anymore. We would be back in the soup again, as far as the NDE goes.

So I sense that that's something we have really to think about in trying to construct this kind of thing: what are the characteristics of the flaws? Let's not assume that's going to be something easy to do or even something we can do.

From the Floor: I'd like to make a comment on the intelligent processing of materials relating to the area that I'm very pleased about, what we call NDE moving in the processing role. But I agree with Bob Gilmore, that in my opinion, before you can have artificial intelligence systems, you have to have a real intelligent person at the start, and that means that you need some expert.

If you look at the viewgraphs that were shown, we see a French chef making some very exotic dish and then they showed some idiot trying to make the same thing for a thousand people, and they figure, give the idiot a computer; he could then make the exotic dish for the thousand people. What they forget is that in many systems that we are trying to work with, there's no French chef to start with.

Dr. Ives: If I might, I have observed that quite often, people versed in NDE are used as firemen.

From the Floor: To fight fires.

Dr. Ives: And it strikes me that Dr. Burte was suggesting, perhaps, a change in roles, whereby NDE would be a very active participant in the design process. Now, from your own experience, could anyone comment upon an experience in your past or your current ativity where NDE is an active participant in the design process?

Dr. Vicky Panhuis (Garrett): All of us in the engine manufacturing business or the air frame business are currently in the throes of using ASIP, Aircraft Structural Integrity Program, or Engine Structure Integrity Program, and NDE is a very active part of design from the very beginning of critical hardware. It's not maybe an area that Dr. Burte is talking about where we have inspectability models or manufacturability models, but we are right there when the designs are being made and the drawings are being done and deciding whether the part is inspectable during manufacturing and all the way through the field. That is happening, at least at Garrett, and I know it's happening at Pratt and G.E. also.

I have one other comment that I want to make before you pose that question, though. I'm very much excited about this concept, and

I realize all the problems with it, and one of the problems I see, as we get more involved in computer technology, is that we have experienced, when we put all our stress analyses on the computer, that we have grown a crop of stress analysts who don't know the problem anymore, that they are very apt to run computer codes over and over again for every single possible case they can think of, with no forethought about what it means to run the code for that particular case.

We have a whole raft of engineers who don't know that what they are modeling is a simple bend test anymore or a tensile test, or whatever. They don't know that because of the access to these computer codes, and they also don't know, when they get an answer, whether it's right or wrong. And I challenge us that if we do put together a system like this, to make sure that we don't create a raft of engineers who don't know whether the answer is right or wrong. (Applause).

Dr. Gilmore: We had the same experience when we were making a presentation to the new Admiral of the Nuclear Navy. Someone who was making an expert system presentation to him was in the middle of defining a very nice format for an expert system, when he thought he heard garbage. And of course, he couldn't have heard garbage, so he kept right on talking, which turned out to be his next mistake. And this was Admiral Keith McKee who was talking.

And what he told us was that he was not too wild about this expert system. He put these computers into Annapolis, and as far as he was concerned, the midshipmen spent entirely too much time playing Star Wars games and not enough time learning about the Navy.

But the other thing that he said is that unless these are handled very carefully, they were going to eliminate the formation of his next generation of experts that he was going to need to maintain the fleet, and he had to have these two-legged experts out there encountering things that had never been seen before with the truly creative ability to assess them, and he didn't feel he was going to get that with expert systems, and I think this is pretty much what Vicky Panhuis just said.

Dr. Buckley: At least, my concept of it is a little bit different. If you have an expert, a "Leonardo da Vinci", you could simply multiply his creativity, his capability. You haven't limited it at all.

Now, maybe we won't have as many people who are carriers of the knowledge passed on, but they weren't doing the creative role. They were assisting in problem-solving. There is a whole body of knowledge that can be provided more easily, which is really what we are talking about, without giving up two-legged expertise in critical roles whatsoever.

Dr. Gilmore: But the creation of this expert is going to depend on the user interface of your expert system, and that's going to have to be modeled, and I think this was the message we were getting.

Dr. Buckley: Those are really important issues.

Dr. Gilmore: So it's impossible to have the computer answer the wrong question.

M. Panhuis: My intention wasn't to say that you shouldn't do this. I'm very much in agreement that it should be done. What I was doing was challenging us to be better at it than we have been in the past.

Dr. Ives: Is it possible that different NDE methods might be of different conflicting design criteria to the designer?

Dr. Gilmore: Certainly.

Dr. Panhuis: Definitely.

Dr. Gilmore: Certainly, not possibly.

Dr. D. O. Thompson (Ames Lab): Can I ask a question that's a little bit off the track you are on here, Gene? It's in answer to either Harris or Jack Lance; some comments you made, Jack, concerning the existence of federal codes and their relation to your maintainability questions and so on.

Are codes in such a format that they could be appropriated -or maybe they are -- at the design point? I was wondering if you could comment on the status of that point.

Dr. J. Lance (Yankee Atomic Electric): Well, in the nuclear power industry, the ASME boiler pressure vessel code section 3 gives you the design code, and that, in some ways, is a problem because that design code is mandated by the federal law and rigidly held and doesn't allow for a lot of flexibility to change.

And that problem was addressed recently -- I don't know if Gerry Posakony is here or some of the people associated with his organization -- was addressed in quite an extensive document that actually looked at some of the inflexibilities of the design codes when they became mandated. Fundamentally, the design codes took the improbables, all of the 10-6 and 10-7 probability events, took those improbables and designed to accommodate them and forgot the operating stresses. And so there had to be, literally, a change, almost, in federal law to get the mistakes out.

Dr. Thompson: This is clearly a very complex question, but I'm wondering if, in a federal code situation, would they ever accept, say, a probabilistic determination of a critical flaw size based on some sort of failure model for that particular system? Would the code follow from the actual structural analysis of the system? Or would the code override everything?

Dr. Lance: No. Up till about two years ago, I think the code would have overridden everything, but there is a new move actually driven by the regulator to look at probabilistic risk analysis in all phases of our operation. So I would think that at least in the nuclear power, we are beginning to lead into a probabilistic approach and that may overshadow the very rigid design rules, or it could.

Dr. Ives: We have a question here.

Dr. A. Notea (Technicon): Yes. Well, it's not really a question. I wanted to comment about some of the problems.

We have a problem for graduates at our university, and most of the participants come from industry. They are either engineers or scientists after the first degree and they are starting to the second and the third, and we push ahead many ways in understanding that NDE should be considered immediately at the design stage in order to save a lot of troubles later. And it's an ultimate goal, of course.

That's why I agree with the more general approach, as was suggested here, where NDE will be part of the design, where options are looked for, so that it will be examined in the part, and later, in the manufacturing. And here, NDE will be involved in the control, and at the last step, of course, in service, when it will supply information about the in-service, from in-service inspection.

All that will supply the required information in order to improve the product. The first product, of course, cannot be an ideal product, so there is a need to improve or to study with time, and I think that the nuclear industry that was mentioned here is a good example of it.

So, that's why I think that the suggestion that was described here by Dr. Burte and later by the people on the panel is a very good one, and really will advance us into a new area of engineering design.

And as for costs and so on that were mentioned here, I'm not sure that we have to take it very seriously, because this program will take a lot of time, and all the costs that we are familiar with and also the ways of design and the approaches to design will change with time. If we are talking, for example, about the year 2000, things will change. We should not look at the future in the same way that we are looking at things that we are doing today or tomorrow. So, NDE in the future will be different, and it will be part of the design.

From the Floor: Lest-we-forget department: the B-1 bomber was designed to a specification, MIL-I-6870, Version C, which imposed a requirement for integrating NDE into the design. And if we look at the history of what happened to this particular specification, it changed to a Version D, E, and F, and for both political and economic reasons, the strength of that document has been lost. Where it was imposed as a requirement, it now is allowed under certain other considerations.

I think it is a case that if our expert systems, artificial intelligence systems, can provde an incentive, then we can be successful. If not, we are not going to be any more successful than we were with MIL-I-6870 C.

From the Floor: Counting off of that comment, I'd like to ask a question of Dr. Burte.

You know, in the government, Harris, they don't do anything without at least an indication of a return on investment. How do you feel that a return on investment can be established for this concept in light of the fact that while we have done wondrous work with our cad and cam to date, the cost of systems keeps going up, not coming down.

Would you comment on that, please?

Dr. Burte: Well, I don't quite know how to comment on that. I stopped beating my wife a while ago. (Laughter).

I think there's been some talk, and I alluded to it earlier -- Mike made it -- and I don't know the answer to it. Now, clearly, this concept is going to require, as it evolves, a whole new way of doing things. It's a pretty frightening thing to think about.

Right now, my understanding of the way we buy systems is that we set a performance goal and we don't diddle too much -- we try not to diddle too much -- with the way the contractor meets that goal. We set regulations that are almost like the force of law, saying "Thou shalt consider maintainability" and all, but we never do. And how are we going to put a warranty on it? What happens if you go bankrupt and the warranty isn't held up? We don't have a weapons system that works. We can't afford that circumstance.

You have to have it work. You can't go and, say, get your money back because you still won't have a weapons system that will work. So there's the problem.

It's probably going to require some way of specifying the ability to predict the reliability and the maintainability and the manufacturability that's quite different from anything we do now, and that may well be one of the most difficult parts of the problem. It's been recognized. But first, we need a little more progress in knowing what we can do. You know, I've been talking about some things that we ought to be able to do, but we have done almost none of it, even in the B-1 case that we just talked about. That was a case where we said, "Let us ensure that the inspectability is at such and such a level to start with." We didn't say, "Let's trade off inspectability versus other things," which is a step beyond that and more difficult. We haven't done any of that yet.

I'm talking about a future goal which I think is reachable, at least, incrementally. But I think it's going to require totally different ways of doing things.

From the Floor: I think we have to be very careful that we don't, with our military specifications such as ASIP, preclude the very synthesis that you are talking about by codifying a procedure which is ossified at the outset and therefore prevents us from doing those very things which you have challenged us to do.

Dr. Burte: There are three dangers in putting things in these systems. You've got Scylla and Charybdis. One is that you've got information gridlock. Second is that the information becomes trivial when you put it in and you regress to mediocrity.

The other thing is what you were just talking about, and let me say again what somebody else said, and I'm trying to say it and should say it again: this is not to take the place of the engineer, the intelligent, creative man -- in no way. This helps him do his job better. And if it's looked at in any other way than that, it's a pretty dangerous thing.

Now, that intelligent, creative engineer -- I use that term "Leonardo" and I use it a little advisedly -- is going to be a different sort of engineer. He's going to be on a higher level than we have now. And I ask some of you guys - Laszlo, are you training guys like that?

Dr. Laszlo Adler (Ohio State): Not yet.

Dr. Burte: But what's it going to take? Because these are multi-disciplinary guys, and that's not a popular thing to try to do.

From the Floor: When we finish the system, possibly real-time, we will do it.

From the Floor: Let me raise one more nasty question along with the last couple. Assuming that we get these systems and we are sufficiently knowledgeable at some point in the future to put a good assessment of risk on our structure or on our engine performance or on our product, we are now talking about, in these cases, life; if it's a commercial aircraft, a lot of lives. Are we actually going to put ourselves in the position of making cost/risk, cost/life trades, as a design engineer?

I guess my premise is yes, we are; yes, we have, for some time, but don't ask us to talk about it because we will deny that we ever considered it. (Laughter).

How do we deal with that?

Dr. Burte: Seems to me we have addressed that problem at excruciating length at the beginning of the retirement-for-cause activity.

From the Floor: We addressed it, but I don't know if we ever answered it.

Dr. Burte: Oh yes we have. Yes, we have. Otherwise, we wouldn't have something like retirement for cause or ASIP or, for that matter, structural integrity programs before that. In other words, sticking your head as an ostrich in the sand is an engineering solution which is going to lose in military strength and it's going to lose in the world competitive market, I suggest to you.

Using the information intelligently might allow you to compete, in all senses. This is my personal opinion. I'm not speaking for the Air Force, but I think the management that doesn't do this, that's afraid to do it, will lose the competitive fight, be it military or be it commercial. And I think well they should.

Dr. Ives: Comment here.

From the Floor: I'd like to raise another question which sort of has been hinted but maybe not directly said, and that is the direct influence of people or engineers or, actually, a culture of engineering.

I think these new advanced systems are requiring the reliability and performance which really cannot be met by a classical engineering sense of hard statistics, of hard numbers, of designs from the handbook, and we are really not bringing up engineers who can factually trade off between failure, between cheating on those statistics, in terms of doing something else down the line, between a preventive medicine.

We have a lot of good surgeons but we don't have the diagnostic capabilities in which those engineers can fairly look at a system and assess it to prevent a catastrophic thing before it happens. I think unless we can take maybe a medical approach towards that problem -- no matter how good we are in NDE and this new tool that you can make these systems more reliable, we have to change that culture in engineering so that people, in fact, have hands-on ability to design those systems.

Dr. Buckley: It still seems to me taht all these institutional issues sort themselves out, but I keep coming up with two fundamental classes of technical issues.

One of them is something that this group spent an awful lot of effort on, and that was how to make good measurements. And I thought Jim rose had a very profound comment when he said, "The pre-existing flaw distribution is going to be critical, and none of this is going to solve that." That problem was there before trying ceramics. It's going to be there forever. I mean, you can pay more money and get more data, but there's going to be that factor, and good measurement models for techniques are still going to be there. None of this is going to change that.

And the other thing that I think is a critical issue -- it's not the right forum to discuss it -- is the issue of consistency of all those new models that you're trying to build together, because if there is inconsistency, you have no assurance that you are going to find a correct answer, let alone anything approaching an optimal answer. And we sort of hinted at those things. I guess I see those as two classical technical issues.

The nice part is that you are going to find out an awful lot of things that you don't know, and didn't realize you didn't know, when you try to put these pieces together. But I'll leave off all the institutional problems.

Dr. Gilmore: I think that we can clarify a lot of things on engineering freedom if we specified that the systems we were talking about were largely going to be command-driven and not menu-driven, because if you work with a command-driven system, then you constantly insert the decision-making capability of the individual who's running the system.

And when you talk about replacing the skill or lack of skill on the third shift with a menu-driven system -- you see, this is what McKee was so angry about. That blunts the ability to develop the expert on the third shift. But if he has a command-driven system with the proper interface, then the system is going to lead him and it's going to make him smart. It's going to improve the person as well as improving the system.

And when Harris talks about the retirement for cause and the ASIP, these were complex things and they were interactive programs, but they were really formulating command-driven systems. And I, for one, won't build an acoustic microscope that isn't a command-driven system. I don't want anybody running one that doesn't want a command-driven system.

Dr. Richard K. Elsley (Rockwell Science Center): I'd like to draw an analogy and make a tongue-in-cheek suggestion. From the beginning of the time of computers, people thought it wouldn't be all that hard to get computers to translate languages, understand natural language, and play chess at the level of a grand master. None of those goals have really been achieved yet, but there are commercial products out there that are doing useful parts of those problems in useful ways for people. That brave new world that Harris has asked us to create may follow a similar pattern. It may not actually be achieved within any of our lifetimes, but useful pieces will come about.

Now, to address the concern about the expert systems becoming a crutch and preventing new expertise from being developed, I would like to suggest that organizations using such systems have in place a substantial cash bonus program for people who can prove that the expert system is wrong. (Laughter). You see, what this will do is either result in the improvement of the expert systems to where they are good enough or put such an economic drain on the organization that they will have to stop using the expert system. (Laughter).

Dr. Clark: Let me make a response to that.

At Westinghouse, we are in, probably, the second year now in commercial application of the expert systems for the interpretation of eddy current data; again, a system designed to, at the outset, assist the field inspector. I think it's critical how you first put the program into place.

After having seen what the tool was capable of doing, I think the bottom line of two years of experience is a real plus in aspects of making the inspectors much better than they were previously. The system that we use has the capability of keeping track of who did what when --also identifying things that haven't been seen before.

That particular aspect of the adventure has been tremendous in that it keeps the expert inspectors on their toes. They express their data in a more common format than they did previously. The inspector-to-inspector communication in different plants has increased tremendously.

And in my own personal opinion, one of the most significant advances of that whole program is that we have a great improvement in credibility between the field inspectors and the so-called experts, because the final package that we put together was very clear to make this thing tick. The field inspectors had as much expert input as the physicists and scientists that fed in from the other end.

So, I don't really have as much concern about these kinds of programs getting out of hand as some of you might in terms of the overall implementation of a rational program. It's worked quite successfully.

Dr. Ives: Don, did you have a comment?

Dr. Thompson: I had a question, but it's going to change the subject. I don't know much about computer-aided design systems. Is the status of computer-aided design such that significant advances have to be made to incorporate these kinds of thoughts, or is it a doable problem from the point of view where you are now?

Dr. Clark: From my perspective, I think we can do it today.

Dr. Ives: Other comments? How do you put together your expert system such that there is appropriate voting when different NDE techniques demand different things of the designer?

Dr. Clark: Let me make it clear, our program is designed at one particular, relatively simple piece of hardware. Steam-generated tubes, per se, are all the same material, same general design, so that we use one system, eddy current, specifically.

Dr. Ives: But is it possible that a different kind of flaw might grow in the manufacturing process by the nature of the process, that the one programmed NDE technique would no longer be applicable?

Dr. Clark: I would tend to doubt that, but there are other problems that have arisen along the lines of deposit formation during service, which would preclude the use of eddy current, and we have, in fact, switched to sonics in some cases. But the interesting thing is that the expert system was telling us that it had to be done before we really noted it.

Dr. Ives: I have my experience of materials not being materials that they were supposed to be. How can you incorporate expert systems to give the designer aid when he's getting conflicting direction from the -ilities? Would you care to comment on that?

Dr. Clark: Yes. That's a real important area of concern, and what we have been trying to do, at our organization, anyway, is we are trying to use NDE technology to assess inherent material properties, not necessarily the presence of void-type defects. And one of the reasons for it is we like to be in a position to be looked on as a more positive contributor to the design stage. I think that's a hurdle we have to get over.

So as a result, we have been doing a lot of first-time assessment of material at a relatively high sensitivity level where we are collecting a lot of information that wouldn't necessarily tie in to some threshold flaw, but we then save that information and do repeat inspections through service and compare one set of inspection data, which is very easy to do now on computers we have, and just move through and try to see changes in the material properties that would be a factor in early development of damage.

It's a very difficult thing to do and it's hard for a lot of operations to appreciate what you intend to do with that data. In other words, some people have negative feelings with regard to inspectability. So we tell them, "We are going to start inspection at a much more sensitive level and keep that data and use that as a base line for in-field inspection at a later time." It's not easy to do because it's hard to deal with people. They must think that it's going to be to their advantage.

Dr. Panhuis: To answer your question a little bit, I think you have to find what your end result is. If you have two inspection techniques that you're going to use -- for instance, ultrasonic inspection of a forging before manufacture into a disk and eddy current after manufacturing to look for surface defect -- and you get conflicting requirements for the design of that part, then you have to look at your final goal. What's you final assessment of that? Is it the estimated life of that part, and which one of those gives you the higher risk to take if you don't have the optimal inspection?

I think that's what has to be taken into account in expert systems like that. If you have conflicting results, you have to look at some kind of a risk factor. After all, that's what we do now in design, when we design the material properties or whatever. There's a risk factor associated with a wide failure rate, and the same thing could be applied here. You have to define that risk before you can decide which one you are not going to optimize completely. That's one way, maybe.

Dr. Clark: The way we have been trying to address that in hardware, again, in steam generator work in particular, we use probes that have both ultrasonic and eddy current sensors and collect the data simultaneously. But what we have been trying to do is the following. On tubes removed from service, prior to metallurgical characterization or what have you, we collect the data with a single unit, four directions of ultrasound, coupled with eddy current responses. And clearly, depending on the nature of the damage, different defects have different value.

Dr. Panhuis: I think his question was more directed at the initial design part, and the design says --if the expert system comes out for ultrasonics, the design should look like this. But for eddy current, it should look like this, which one do you go with?

Dr. Clark: I appreciate your concern. The problem I'm looking at is that the original design position was that you never have any damage. It just sits there. We have 26 different kinds of damage.

Dr. Panhuis: This is in the future, from now on.

Dr. Clark: Well, you have to face the real world. There are many problems out there that are sitting there looking for attention today, as well as all the new concerns to worry about. I think what we have to do is be able to integrate both the in-service characterization of our hardware as well as capturing that information, feeding it up front to the early design. I think it's all one big picture. It doesn't necessarily get looked at that way, but it's a whole concept.

From the Floor: I had several thoughts that came to me. One was the engineer's associate that Dr. Burte spoke about. It seemed to me that that could be modeled as a network of expert systems. It's a mini network of separate expert systems. I think that's an interesting way of viewing it.

Secondly, how in the world do you go about thinking about how you network systems? We haven't even got the ability to build one yet very well. We don't have to worry about the answer yet because we've got to handle the first problem first. But if you want to know some of the problems that you will be faced with on networking, get in and study the problem that you go through when building the single expert now. Westinghouse has got an expert system program going.

Maybe it would be advisable to put a programmer in the background to observe the processes to go in that system, simply codify it; what are the experiences that you get through. I think if you start to assimilate some of that data, you might start seeing a trail that you are going to have to be following in the future.

Dr. Clark: Exactly. That's what we are trying to capture.

Dr. Ives: For a given NDE technique, are probability of flaw detection spaces reasonably well defined today? For a given NDE technique, in order for data from that technique to be useful in the model, as Dr. Burte suggested, it seems to me that the spatial characteristic of probability of detection needs to be defined. It's not a single-value D function, right? It depends on the size of the flaw and the depth of the flaw and the aspect of the flaw. So, is the probability of detection of flaws, in that spatial sense, reasonably well-characterized today for various NDE methods?

From the Floor: You know, I think that's the problem -- maybe you hit it. This conference is called Quantitative NDE. By and large, NDE right now is qualitative. That means we have the mechanics; we have the ability to model things in the exact sense of materials response. NDE is such that it basically says, "Make me a specimen which looks somewhat like what I need to look at, and I'll tell you it works." Now, that's really hard to model in an intelligent system, expert system. In fact, it's impossible.

I think the gas turbine engine is a very specific case. You take a composite structure, the main frame of an aircraft, a wing, and somebody gives you a drawing and says, "How would you inspect it, and what is your ability to find such and such a flaw?" The only thing you can do is to pull your hair until somebody gives you a specimen, and you do something with it.

From the Floor: Lockheed did a study program for the Air Force called "Have cracks, will travel." They generated some simulated structure with deliberately induced fatigue cracks and carried those specimens to various locations throughout the depot-level Air Force and determined what the inspection probabilities were for those methods, for those structures, and for those locations. They were decidedly less than we hoped and varied rather grossly from one location to another. Yes, it's possible to quantify them, but the result of that was a drive towards automated inspection systems, where you get uniformity.

Dr. Ives: There is a challenge from that to this community?

Dr. Ward Rummel (Martin Marietta): Well, maybe I can address that. I think there's a challenge. I'm not sure we know how to use it. But for instance, we heard in a session today, with the new RFC system, we can see flaws five mills deep. Now, if I put that in my model and I need to build one satellite, as we do in our own company, how do I communicate that I'm not going to use that same criteria for one satellite because not only is it not applicable in the near term; it would not be applicable for the satellite at all in the time frame and certainly not within the cost frame?

So, some way, we have to put information in that takes into account the resource availability or practicality and the cost of doing that, because in the case of the satellite, I'm going to take a more expensive route to design out the need to do an inspection of that kind, where I may not do it if I had many, many parts.

So, it's not a simple plug-it-in-the-table-and-look-it-up-later that's applicable for all problems. It just doesn't work that way.

From the Floor: Let me add one more complication. These kinds of numbers are very geometry-sensitive. So if you specified the particular geometry that you're going to inspect in great detail, you can probably end up with a pretty good probability number on it, but you are very hard-pressed to generalize that without that specific geometry determination.

From the Floor: Another major concern is that very often, the inspection procedures we use are designed either to detect or to characterize. Our experience clearly has been those tools we use to characterize may not work for detection, so you've got to decide which route you are taking. And that can be a really serious problem because the detection tools are so different.

From the Floor: In fact, an example is, I think, the B-1 aircraft. It was brought up here before as a fracture critical design. One of the things I know is that the area of specification and the experience of NDE for ultrasonic testing of the honeycomb. The design is 12 inch-thick stabilized honeycomb with composite skins and composite core. But this was the specification because that's how it was read out of the manual. Now, it makes no difference. That was a black-and-white page in a specification; it was a lot of headaches in NDE. Now, we have a design, 12-inch-thick honeycomb, and we make it, inspect it, and fly it.

Dr. Ives: Dr. Burte, do you have any questions for the panel or for the audience?

Dr. Burte: I asked mine. Dale, is there anything you want to ask?

Dr. Dale Chimenti (AF Materials Lab): Is there any possibility that at some point, the modeling of the P.O.D. process leads us in a direction where the connection between the modeling and the optimization of the inspection process becomes a problem?

Dr. Buckley: You must be thinking of some potential problem.

Dr. Chimenti: Well, a model, for example, may become too complicated to optimize easily. If it's partly heuristic and party deterministic, how does one then use it in a predictive sense?

Dr. Buckley: Given a problem, most analysts will do the simple model on critical parts of it. If you are trying to model ultrasonic propagation of a complex structure, you are probably just going to do some simple calculations at critical points where they are changing rapidly, things like that.

Well, why can't you attack the problem just that way, and have heuristic rules to look for where to do the simple calculation instead of doing the whole thing? And I think that's a fairly rational approach. You have to be careful with those rules, but that's what the analyst does anyway.

Dr. Chimenti: That's assuming the process is sequential, that you can start at one point with the heuristic rules and then eventually lead to a point where you simplify it, in a certain sense, sufficiently now to be deterministic.

Dr. Buckley: Yes.

Dr. Chimenti: Would that always be the case?

Dr. Buckley: No. Not necessarily, but I don't know.

Dr. Clark: Well, I think one of the things you've got to watch is to tie your modeling capability to your service experience. I hate to dwell on that point, but I've seen too many cases. A good example I've seen is in turbine disks. I can show you dozens of disks where the material environment, what have you, decided to defy the rules of modeling and develop cracks in the free port, ignoring the stress.

So any of these models, I think, have to be specific in terms of the application that you are looking at, and make sure you have an adequate amount of feedback from the field. A lot of the problems we have are created because the designers have put these things together, and the materials people didn't ever envision the potential problem, so there wasn't much in the way of inspection at the time it should have been done. As a result, we are caught up in the situation now where we have a lot of hardware that's very difficult to inspect. The problems develop from there.

I think that field performance is abolutely critical. And at least in our industry, through EPRI, we tried to coordinate with different utilities on problems at one time or another. Essentially, we have a central area where we can collect that information to see how the industry is pursuing it, how things are happening. And without that, modeling is really tough. Verification of the modeling is tough.

Dr. Ives: Well, I'd like to thank Dr. Burte and the panelists, and that's the end of the session tonight.
(Applause)